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Decision tools for coral reef managers: Using participatory decision support to integrate potential climate impacts and informed decision making

Pamela J. Fletcher [a,b,c,*], Michael Spranger [d], James C. Hendee [c], Yuncong Li [b], Mark Clark [e], Gregory A. Kiker [f,g]

[a] University of Florida, Florida Sea Grant College Program, 803 McCarty Drive, Gainesville, FL 32611, United States

[b] University of Florida, Tropical Research and Education Center, Soil Water Science Department, 18905 Southwest 280th Street, Homestead, FL 33031, United States

[c] NOAA, Atlantic Oceanographic and Meteorological Laboratory, Ocean Chemistry and Ecosystems Division, 4301 Rickenbacker Causeway, Miami, FL 33149, United States

[d] University of Florida, Family Youth and Community Sciences Department, PO Box 110310, Gainesville, FL 32611-0130, United States

[e] University of Florida, Soil Water Science Department, 2181 McCarty Hall A, PO Box 110290, Gainesville, FL 32611, United States

[f] University of Florida, Agricultural and Biological Engineering Department, PO Box 110570, Gainesville, FL 32611-0570, United States

[g] University of KwaZulu-Natal, School of Mathematics, Statistics and Computer Science, South Africa

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ABSTRACT

The decline in coral reef health presents a complex management issue. While several causes of decline have been identified and are under continued study, it is often difficult to discern management actions necessary to address multiple near- and far-field stressors to these ecosystems. As a result, resource managers seek tools to improve the understanding of ecosystem condition and to develop management responses to reduce local and regional pressures in the wake of larger, global impacts. A research study conducted from 2010 to 2014 in southeast Florida, USA consisted of two objectives: (1) conduct a needs assessment survey with coral reef and marine resource managers to identify data needs and the preferred design and delivery of climate information; and (2) develop and evaluate prototype decision support tools. The needs assessment process was helpful for identifying the types of climate information managers would like to obtain to inform decision making and to specify the preferred format for the delivery of that information. Three prototype tools were evaluated by managers using pre/post surveys that included hands-on tutorials to explore the functionality of each. Manager responses were recorded using a five-point scale with 1 being *No* or *Not Useful* to 5 being *Absolutely* or *Very Useful*. The median responses rated the usefulness of the tools (4), if they would consider using the tool (4), and if they would recommend using the tool to other managers (4 or 5). The median response for increasing manager's knowledge about climate impacts after completing a tutorial of each of the climate tools was a 3 (moderately useful). Of the managers surveyed in the pre/post-survey, all but one stated they believed they would use the decision support tools in the future with the single response due to wealth of data availability in their institution.

* Correspondence to: NOAA, Atlantic Oceanographic and Meteorological Laboratory, Ocean Chemistry and Ecosystems Division, Florida Sea Grant, 4301 Rickenbacker Causeway, Miami, FL 33149, United States. Tel.: +1 305 361 4553.

E-mail address: Pamela.Fletcher@noaa.gov (P.J. Fletcher).

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1. Introduction

Coral reefs throughout the world are in decline (Wilkinson, 2000; Bellwood et al., 2004; Carpenter et al., 2008). The Florida Reef Tract located along the southeastern portion of the Florida peninsula is no exception to this deterioration (Gardner et al., 2003; Donahue et al., 2008). Multiple pressures to coral reef ecosystems have been documented with one of the primary influences stemming from increased temperatures associated with climate change (Hoegh-Guldberg, 1999; Gardner et al., 2003; Hoegh-Guldberg et al., 2007; Carpenter et al., 2008; Wagner et al., 2010; Lirman et al., 2013; Nuttle and Fletcher, 2013a,b,c). Advances in monitoring reef health and management strategies have been implemented (e.g., designations from unrestricted use to no-take reserves in the southern portion of the Florida Reef Tract); however, local management of impacts from far-field drivers such as climate change still exists (NOAA, 1996, 2007; Keller and Donahue, 2006; Donahue et al., 2008; Keller et al., 2009; ONMS, 2011; Nuttle and Fletcher, 2013a,c). For the latter, managers can do little to address the direct causes of reef degradation from far-field pressures which impact reefs within their jurisdictions. With climate, one option to address this challenge is to provide easier access to information. Improving the understanding of climate impacts may help identify management actions within the intersection of biophysical, institutional, and human dimensions science at the appropriate geographic scale to effect significant positive change in coral reef health.

Managing natural resources in a highly developed, urbanized area under the influence of climate change is a complex environmental problem characterized by multiple stressors and stakeholders with no easy solution (Batie, 2008; Balint et al., 2011). This may be due to the region's appreciable geographic scope or barriers to social, cultural, or economic desires, often involving multiple stakeholders which are constantly evolving within a coupled socio-ecological system (Churchman, 1967; Rittel and Webber, 1973). Resource managers must rely upon the best available science to make sound management decisions while responding to diverse stakeholder needs that can be driven by special interests, values, and desires (Conklin and Weil, 1997). One approach to address these dynamic socio-ecological systems is to incorporate participatory decision support into the management process. This can be both trans-disciplinary and adaptive and aid managers in designing and evaluating socio-ecological management alternatives (Goosen et al., 2007; Kiker et al., 2008).

Participatory decision support refers to a process of bringing people, sometimes called stakeholders (i.e., those with a stake in the outcome), together to develop a solution, idea, or concept to take action in the future (Sheppard, 2005; Raymond and Cleary, 2013). Stakeholders are individuals who have an interest in an issue and are critical components in the decision process (Ramirez, 1999). Pomeroy and Douvere (2008, p. 816) described the importance of stakeholder involvement in the decision-making process within the context of marine spatial planning as: "understanding of the complexity of the ecosystem; understanding of the human influence on the ecosystem and its management; examining the compatibility and/or (potential) conflicts of multiple use objectives; identifying, predicting, and resolving areas of conflict; and discovering existing patterns of interaction". As such, participatory decision support is a valuable tool for planning and managing resources due to the robustness of data and information shared during the process; the transparency of the approach reaches across disciplines and helps bridge the gap in applying science to management decisions. When carefully designed, the participatory decision support approach can be useful for achieving agreement among diverse stakeholder groups. The method has the potential to integrate highly technical knowledge from scientists with the varied knowledge and values of non-scientists to make better informed decisions and to provide reasonable assurance to justify those decisions (Lynam et al., 2007, 2010).

This paper describes a participatory decision support methodology used to guide the development of climate information tools for coral reef managers in southeast Florida within the construct of three components: people, process, and tools (Kiker et al., 2005). Each component is critical to obtain stakeholder input and to build a sense of ownership and commitment to the use of the products or results from the effort. From January 2010 to May 2014, stakeholders consisting of both end users of the information and developers of climate information tools participated in a climate information needs assessment survey, information exchanges between researchers and managers, and a pre/post survey to evaluate the utility of prototype climate information tools. Accordingly, the paper addresses the following objectives:

1. Review the participatory decision support methodology used within the context of people, process, and tools described by Kiker et al. (2005);
2. Identify climate information needed by resource managers; and
3. Survey and assess resource managers' reactions to prototype decision support tools.

Consequently, this paper is divided into three parts. The first section outlines the participatory decision support methodology within the context of people, process, and tools. The second highlights the climate information needs that emerged from the cooperative effort and participant reactions to the prototype tools. Finally, a discussion section sums up the lessons learned and highlights the next steps in this participatory decision support process.

2. Materials and methods

Participatory decision support uses a bottom-up iterative approach that allows for stakeholder input, research science, action, reflection, and communication (Sheppard, 2005; Raymond and Cleary, 2013). A needs assessment survey is one approach to achieve participatory decision support that identifies interests, capabilities, and the evaluation of outputs. The method consists of planning, data collection, data analysis, and reporting as described by Witkin (1995),

Altschuld and Witkin (2000), and the National Oceanic and Atmospheric Administration's Coastal Services Center training manual for Project Design and Evaluation (NOAA/CSC, 2003). The coral reef and marine resource manager climate information needs assessment in south Florida was achieved by integrating three components: people, process, and tools (Kiker et al., 2005).

2.1. People

People are an essential component of participatory decision support research. In this study, three types of participants were identified: (1) coral reef and marine resource managers in southeast Florida (end users) who would be vested in decision support products; (2) researchers developing prototype climate information tools; and (3) a coordinator to liaise between the end users and researchers.

2.1.1. End users

Nineteen managers representing 15 resource management offices participated in the project between October 5, 2011 and February 25, 2014. The first step in identifying managers was to meet with staff from several of the resource management offices in southeast Florida. Informational interviews were conducted with representatives from five state and local agencies between October 5, 2011 and October 21, 2011. From these interactions, key informants were identified and contacted to confirm interest in participating in an assessment survey to examine climate information needs for managing the Florida Reef Tract. A climate information needs assessment survey was implemented between December 16, 2011 and May 17, 2012. Fifteen individuals provided information and insights regarding managing resources along the reef tract that included climate information needs and a preferred format for the delivery of that information. Finally, 11 resource managers completed pre/post surveys to evaluate prototype climate information tools from January 8–February 25, 2014. Throughout the project period, interactions with end users consisted of facilitated focus group sessions, workshops, and one-on-one meetings. These meetings are described in greater detail in Section 2.2 Process of this paper.

2.1.2. Researchers

Researchers were those individuals using climate data to develop tools or models for interpreting climate impacts on coral reef ecosystems. Ongoing research projects were leveraged and used as prototype climate information tools in this project.

Four researchers were identified as potential contributors. These individuals participated in climate workshops held in Miami, Florida, USA on January 11–14, 2010 or August 15–16, 2011. Consultation with these researchers in early 2012 resulted in the inclusion of prototype climate information decision support tools in the assessment survey. Prototypes were produced and shared with managers to gather feedback on the usefulness of these products for improving the understanding of climate impacts to reef and marine resources for informed decision making.

2.1.3. Coordinator

The coordinator was the project liaison acting as a boundary organization linking end users with researcher capabilities throughout the project (Batie, 2008). The coordinator used the needs assessment process to implement participatory decision support (NOAA/CSC, 2003). Interactions between and among researchers and managers were organized in part, or entirely, by the liaison. All project surveys and reports were completed by the coordinator.

2.2. Process

A needs assessment survey was completed as a first step in understanding what was *needed* by the target audience. Assessments help guide project design, implementation, and evaluation. They include: stating the issue and intended audience; establishing a planning team; providing information and a literature search; characterizing the audience; establishing goals and objectives of the needs assessment; and selecting data collection methods (Fig. 1) (NOAA/CSC, 2003).

2.2.1. Stating the issue and intended audience

Preliminary information was gathered during a climate and marine protected area workshop that was held on January 11–14, 2010 in Miami, Florida, USA. The purpose was to bring together researchers, managers, and academic partners who expressed their interest in collaborating to develop a suite of climate information tools for resource managers, the latter being the target audience. The workshop was attended by 28 individuals. Meeting notes were used to identify researcher capabilities, consistent terminology (e.g., defining what constitutes climate data), and manager perspectives with two key points: managers need climate information that is easy to understand and access, and resource managers in southeast Florida are the target audience for piloting the design and delivery of this information.

	JANUARY 2010	AUGUST 2010	SEPTEMBER 2010-SEPTEMBER 2011	OCTOBER 2011	NOVEMBER 2011-MAY 2012	JANUARY 2014-MAY 2014
PROCESS COMPONENT	***Stating the issue and intended audience***	***Establishing a planning team***	***Information and literature search***	***Characterizing the audience***	***Establishing goals and objectives of the needs assessment***	***Selecting data collection methods***
ACTIVITIES	Hold climate information workshop with researchers and managers	Facilitate group session with researchers and managers	Gather information during meetings, conferences, workshops	Conduct informational conversations at regional management offices	Design and administer a resource manager climate information needs assessment	Design and administer a pre/post test to evaluate manager perspectives of a prototype climate information tool

Fig. 1. Timeline of needs assessment process components and activities used to complete climate information tool development for the Florida Reef Tract.

2.2.2. Establishing a planning team

Following the climate and marine protected area workshop, several exchanges among a smaller group of participants continued. This smaller group formed a planning team and organized a workshop with specific goals to (1) outline current research on corals and climate, and (2) identify opportunities to integrate this information into existing marine protected area management activities. A corals and climate workshop was held on August 15–16, 2011 in Miami, Florida USA. Fourteen individuals from government offices and academic institutions presented and shared information on current research and strategies to develop climate tools for reef managers. The planning team used workshop discussions to identify tools to present to managers and to outline a series of questions asking managers what they need to incorporate climate into their decision making.

2.2.3. Characterizing the audience

Informational conversations were conducted with 14 individuals from five management offices in the region. The purpose of these meetings was to document the current use of climate information within each office. The meetings also served to identify the individual most likely to use climate data in their decision-making and thus identify the most appropriate person to complete the needs assessment survey in the future. The informational conversation format was structured to present the project concept, learn about current climate-related activities in each office, and identify a key informant or point of contact in each office. There was no formal agenda to allow for open-ended conversation and the exploration of ideas and information. The discussions lasted between one to two hours. Participants identified specific individuals from their office as key informants for this study. The key informants were contacted to confirm they: (1) played a role in managing coral reef and marine resources; (2) identified resource protection mandates their agency was responsible for implementing; and (3) expressed an interest in participating in the needs assessment survey.

Researchers were also considered part of the audience in this project because of their involvement in not only developing tools, but also in receiving feedback about their products from resource managers. Researchers were selected using two criteria: (1) the individual was conducting climate-focused oceanic or atmospheric research; and (2) the individual's study site included a portion of, or the entire, Florida Reef Tract.

2.3. Selecting data collection methods

Once the audience was characterized, data collection methods were selected. A needs assessment survey and a pre/post survey were chosen. Both were conducted with coral reef and marine resource managers in the region and were used to gather information about climate information needs and to gather input for the design and delivery of climate tools.

A needs assessment survey was selected to validate the need for climate information and to gather specific information on the preferred design and delivery of the tools. The survey consisted of 23 open-ended questions (i.e., questions that allowed the respondent to provide thought and detail in a response compared to a yes or no answer) and three examples of prototype decision support tools. The questions were divided into two categories. The first set of questions was designed to gather general marine resource management information and background on the resources within each participant's jurisdiction. The second set of questions asked about climate information needs and the preferred delivery of that information. Climate information prototypes were included to gather a first impression of the types of tools being developed and to obtain feedback to refine or improve the products for ease in use and interpretation.

A pre/post survey was designed to gather attitudes and beliefs about climate information decision support tools where participants could choose between five responses (e.g., 1 = not useful, 2, . . . , 3 = moderately useful, 4, . . . , 5 = very useful). The survey included five pre-test questions, a tutorial for using three prototype tools, and seven post-test questions. The basis for the use of this format was to assess the participants' level of agreement or disagreement related to a series of questions about the prototype tools.

Data collection was carried out in person, by phone, or using Internet conferencing (GoToMeeting, 2015). Questions were asked and responses recorded on paper or were submitted electronically through E-mail. Each interaction took an average of one to two hours to complete. Responses were transferred into a spreadsheet and ranked with those most frequently mentioned responses placed at the top of the list and those mentioned the least at the bottom of the list. Pre/post survey data were entered into a spreadsheet, and a median was calculated to show the central tendency of responses (Boone and Boone, 2012).

2.4. Tools

Three prototype decision support tools were identified for use in the needs assessment survey. The coordinator included these prototype products to obtain feedback for further development following the informational conversation phase of the project. The first product was a sea surface temperature map that provided spatial visualization of the potential for coral reef bleaching based on increased temperatures (van Hooidonk et al., 2014). The second product was a weather-typing map developed to identify relationships between weather patterns and the presence of elevated chlorophyll levels in the water column as detected by satellites (Sheridan et al., 2013). The third product was a monthly onshore reef flux report created to explain the movement of nutrient-rich deep water onto the nearshore shelf or reef system (Gramer et al., 2008). This report provided background information on the monthly onshore flux, and an automated system provided electronic (E-mail) alerts detailing changes in water quality along the southern portion of the Florida Reef Tract. Feedback gathered during the first needs assessment survey was documented in a National Oceanic and Atmospheric Administration (NOAA) Technical Memorandum (Fletcher and Hendee, 2012).

The results of the needs assessment survey were shared with the planning team and researchers. From this, a new survey using the three decision support tools was developed. The tools consisted of the Degree Heating Weeks model from the needs assessment survey (van Hooidonk et al., 2014) and two additional products. One tool, a Web site called the Coral Health and Monitoring Program (CHAMP) (http://www.coral.noaa.gov/champportal/), was redesigned based on manager feedback in the needs assessment survey. CHAMP is based out of NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML). CHAMP is a comprehensive Web site that includes research, data, and resources to improve the understanding of coral reef ecosystems around the world. The CHAMP portal provides *in situ* and remotely-sensed data collected at coral reef locations around the globe. The redesigned content of the portal includes a user's guide, a map-based query tool showing coral reef monitoring stations, and a feature to download data (Fig. 2). At the time this research study was being conducted, the Web site was scheduled to be updated. The project coordinator was also located at the laboratory and selected CHAMP as one of the tools for timely and efficient stakeholder evaluation. The second tool was a Bayesian Belief Network (BBN) that incorporated climate impacts on coral reefs (Riegl et al., 2013; Fletcher et al., 2014). BBNs are probabilistic models that can assimilate stakeholder knowledge and uncertainty into decision making (Cain, 2001). They are a visual, transparent representation of an ecosystem and can use qualitative (high, medium, low) or quantitative information. BBNs can also be used in participatory decision support to identify the convergence or divergence of stakeholder opinions in the decision-making process.

2.5. Evaluating climate information tools

The pre/post survey for the three climate information tools was completed from January 8–February 25, 2014. The survey was completed by 11 resource managers in southeast Florida, all but two of whom had participated in the initial needs assessment survey. Ten of the surveys were completed in person and one was completed using online conferencing (GoToMeeting, 2015). One session included three individuals working for the same agency; however, each had a different management role so were evaluated individually.

The pre-test survey began by asking managers about their decision-making process. The purpose of these questions was to obtain insight about how decisions were made, identify the respondent's role in the process, and explain where and how data were applied to decision-making. Respondents were asked to identify their manager type from a list of possible options (e.g., program manager, project manager, manager, researcher, or other). This question was developed as a direct response to listening to the varied responsibilities of the individuals who participated in the needs assessment survey and to determining if there was a specific type of tool that was preferred by a particular type of manager. The third question asked how often managers accessed climate information to complete work-related responsibilities. The final three questions on the survey were tailored to identify if managers: (1) thought decision support tools would be useful for making management decisions related to climate impacts to marine resources and coral reef ecosystems; (2) would consider using decision support tools describing pressures and stressors to marine resources and coral reef ecosystems in future management decisions; and (3) would recommend using a decision support tool to other marine resource managers within their management portfolio. Optional responses consisted of *yes* or *no* or a five-point scale response (1 = not useful, 2, . . . , 3 = moderately useful, 4, . . . , 5 = very useful, or 1 = No, 2 = Doubtful, 3 = Maybe, 4 = Likely, 5 = Absolutely). Respondents were encouraged to elaborate on their responses to each question.

The next portion of the pre-test survey was the tutorial section. Each tutorial included a brief overview of the product and a series of steps for managers to explore the tools. For example, in the case of the CHAMP Web site managers were asked

Map-based Query Tool

First Impressions

The Coral Health and Monitoring Program (CHAMP) is a web presence (http://www.coral.noaa.gov/champportal/) that highlights the integration of satellite, in situ, modeled, and other sources of meteorological and oceanographic data in near real-time for the purpose of eliciting ecological forecasts for coral bleaching and oceanographic events with the capability to extend to other marine environmental events. These ecological forecasts, or "ecoforecasts," are aimed at informing policy and management decisions. CHAMP developers are interested in updating the map-based query tool for resource managers in southeast Florida.

For the next series of questions, please explore the CHAMP Web site using the Molasses Reef site as an example of what the site contains and its layout. Let's imagine we want to see the SST at Molasses Reef on two specific days. Select the Molasses Reef location from the *Station/Sensors* section of the page. Select monitoring data for that site by highlighting parameters (hold shift and select several) and then right-mouse click to display the last 180 days of data. Examine the *Plots* to the right of the map. There are two tabs, one is *User Guide* the other *Plots*. Scroll down until you see the SST plot. Put your cursor over the blue line to see dates and temperatures representing peaks and valleys in the graph. Locate the high temperature for September 12, 2013 (30.46°C). At the bottom of the page you will find the *Data* display showing all of the monitoring information for that site. Download the data in comma-separated values (CSV) by clicking on the *Download* tab and saving to your computer. Open the file in Excel and look for the SST value on July 23, 2013 (29.88°C). If you need assistance, select the *User Guide* located on the right panel of the page.

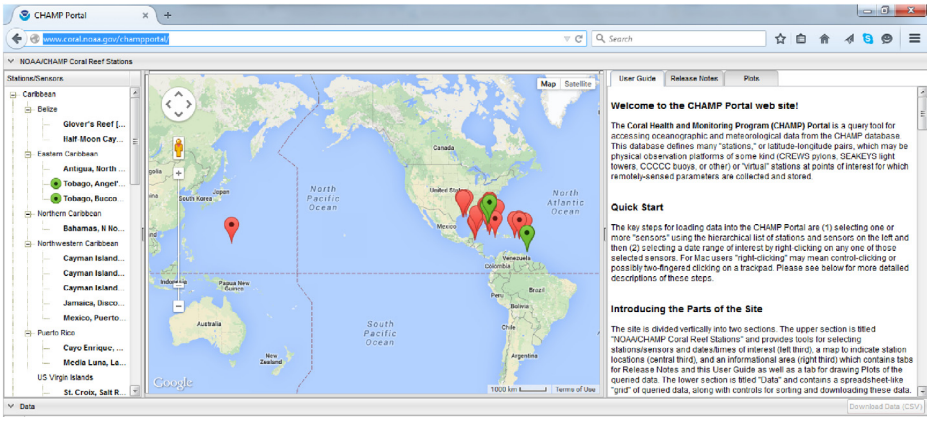

Fig. 2. Sample of the Coral Health and Monitoring Program (CHAMP) map-based query tool tutorial used during the pre/post survey.

to look at a particular coral monitoring station and the data contained on the Web site (Fig. 2). They were instructed to look at temperature data for a particular date and time and to download the dataset associated with that information. They were also asked to explore a user's guide. A post-test survey was administered after the tutorial.

The post-test consisted of seven questions; three were identical to the pre-test. Two of the questions were designed to conduct a long-term assessment of the decision support tools and will be reported in another research paper. The final two questions on the post-test were structured to identify if the tool increased the respondent's knowledge of climate impacts to coral reefs and marine resources and if the manager believed they would use the tool in the future. A five-point scale was used for the former (1 = not useful, 2, . . . , 3 = moderately useful, 4, . . . , 5 = very useful) and a *yes* or *no* response for the latter.

3. Results

3.1. Resource manager needs identified

Informational conversations with the broader group of individuals working in resource management and climate research provided general information about the breadth and extent of each management office and the individuals involved climate-related activities. The informational conversations provided a plethora of information about manager interests, concerns, data needs, and preferred delivery format. The need for more monitoring, research, and synthesis was consistently voiced by all offices.

Table 1
Marine resource data currently used by the 15 managers participating in the needs assessment survey. Numerical totals show most frequent mention of data used by managers. A "1" was assigned for each occurrence, "0.1" was assigned for ancillary mention of the listing (e.g., in another portion of the survey).

Marine resource data currently used	Frequency of use
Peer-reviewed journals	6
State guidance documents/best management practices	5.2
Listserv/forums (topics: harmful algal blooms, turtles, corals)	5
Visuals/resource mapping/benthic habitats	5
GIS/GoogleEarth/Everglades restoration/database (geodatabase)	5
Office committees/regional teams/personal communications (focus on topics)	4
Damage minimization procedures or recommendations	3
NOAA protocols/guidance documents	2.5
Personal observations	2
Real-time data	2
University research	1.5
Southeast Florida Coral Reef Initiative	1.2
White papers	1.1
American Association of Underwater Scientists newsletter	1
Florida Reef Resilience Program	1
On-the-ground programs producing information (data and delivery process)	1
Web-based reporting (e.g., NOAA/ICON, Bleachwatch)	1
Monitoring protocol manuals	1
Conferences	1
SST data from NOAA web page	1

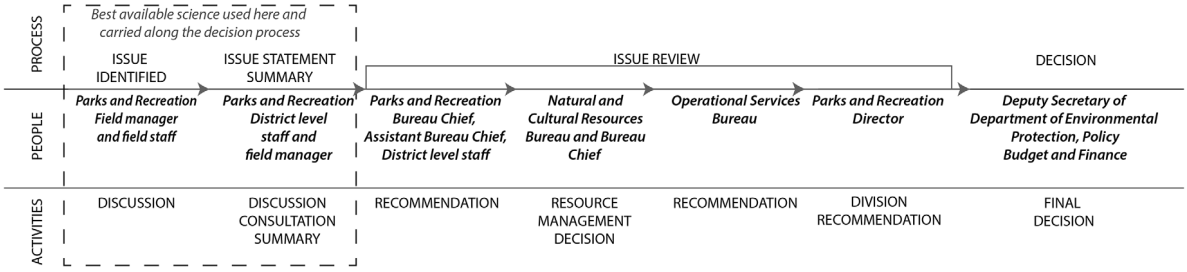

Fig. 3. Cognitive map showing the decision process at a management agency in Florida.

Fifteen managers participated in a coral reef and marine resource manager climate information needs assessment survey for the Florida Reef Tract within the project boundary stretching from St. Lucie Inlet to Key West, Florida (Fletcher and Hendee, 2012). Three of the managers provided a single response from their office, making a total of 13 assessments. However, the responses on this survey were recorded individually because each manager was responsible for a different spatial domain consisting of a state park, state recreation area, and a regional management program, resulting in a total of 19 managed areas within the study site (FDEP, 2014). The results are shown in a listing of climate information currently used (Table 1), needs identified by managers (Table 2), information that is difficult to obtain or interpret (Table 3), and recommendations for designing an Internet-based discovery prototype for climate decision support tools (Table 4) and its delivery (Table 5). In addition, ancillary information was reported to guide the development of climate information tools. The top three data needs the managers categorized as difficult to obtain and interpret consisted of sea level rise/tides/slosh modeling, temperature data, and Gulf Stream current movements (Table 3). This information was identified as useful for making climate-related decisions.

The information shared during conversations far exceeded any of the questions on the needs assessment survey or the pre/post-survey. This information was recorded but not included in the survey reports or publications. However, it was helpful to form the foundation for future activities and to explore additional insights into the management of marine and coastal resources. These included a broader approach to managing coral reef resources beyond climate and looking at the multiple lines of pressures and stressors by which managers can respond and intervene. One such instance was the development of a cognitive map for the decision-making process at one of the regional management agencies (Fig. 3). Gaining insight into the decision process can identify where managers are able to intervene and, if coupled with appropriate tools, aid in decision making.

The needs assessment process was a fundamental variable in describing the varied level of a stakeholder's responsibility in managing resources. It is a critical element in understanding the type of information needed by managers to support their decision making. Insights from listening to remarks during the informational conversations and the needs assessment survey led to the inclusion of a question in the pre/post survey that asked managers to define their management role(s). The purpose of doing so was to recognize manager motivations for needing or using climate information within the broader understanding of managing marine and coastal environments. During the pre/post survey, verbal comments such as "I

Table 2
Climate information needs identified by 15 managers participating in the needs assessment survey. Numerical totals show the frequency each was mentioned during the assessment. A whole number "1" was assigned for each occurrence, "0.1" was assigned for ancillary mention of the listing (e.g., in another portion of the survey).

Climate information data needs	Frequency of mention
Data from peer-reviewed literature	5
Monitoring information delivered via web	5
Temperature (SST and at depth in some cases)	4.1
Science recommendations (being discussed in "4-County compact")	3
Current research findings (quick, easy access)	3
BMPs	3
Damage minimization procedures or recommendations	3
CO_2 in atmosphere	2
Tides/sea level rise	2
Scenario/predictive tools to get concepts across to audiences	2
Weather (including air temperature; patterns of rainfall from climate change and impacts on water supply and delivery to the coast)	2
Agency Web site data	1.1
Online videos about climate science	1
Impacts to marine resources	1
Intergovernmental panel on climate change	1
Finer scale/spatial resolution compatibility (GOMEX to Keys) to get local and regional perspectives	1
Reef crest data	1
Gulf stream movements (eddies and currents)	1
Peer-reviewed data	1
Visualizations (e.g., CanViz) for South Florida	1
Science-based information for sharing with the public	1
Present data with a balanced view	1
Data that has verified and good references	1
Florida Reef Resilience Program data	1
Precipitation	1
Data to help manage resources (e.g., artificial reefs as management do/not help address climate change concerns)	1
Analysis and trends in wildlife—data reports showing increases or decreases in habitat, etc.	1
USGS groundwater data (salt water intrusion)	1
NOAA long-term data sea level records	1
NPS records	1
Long-term salinity	1
pH	1

Table 3
Climate information that is difficult to locate or interpret as identified by resource managers during the needs assessment survey. A whole number "1" was assigned for each occurrence, "0.1" was assigned for ancillary mention of the listing (e.g., in another portion of the survey).

Climate information that is difficult to locate or interpret	Frequency of mention
Sea level rise/tides/slosh models	5.1
Temperature (downscaling)	3.1
Gulf Stream information/patterns	3.1
Weather stations	2.1
Climate information that can be downscaled to this region of the world	2
Rainfall patterns	2
More meteorological data	2
Water quality (nutrient levels; detection limits; microbial activity)	1.1
DBhydro (water quality database housed at regional water management office)	1.1
Physical oceanography	1.1
Subset of CMAN station information	1.1
Current/accurate/regularly examined	1
Changes in reef species and other biological data	1
Atmospheric CO_2	1
Benthic mapping (expansion of *Dendrogyra*)	1
Ocean acidification	1
Linking human activity to impacts	1
Integrating what we know to impacts	1
Vulnerability analysis (e.g., sea level rise using climate scenarios)	1
Airport	1
Fisheries data of all life stages (younger year classes) to help make management decisions	1
All physical measurements	1
Water Management District data (rainfall, etc.)	1
In situ observations	1
pH	1

Table 4
Recommendations for the design of a climate information decision tool from the needs assessment survey.

Recommendations for the design of climate information	Frequency of mention
Visuals (appropriate graphs and maps)	6
Time scales (10 yr, 15 yr, events)	5
Regional scale (entire Florida Reef Tract)	4
Improve data (more water quality monitoring data)	2
Webinars	2
App for climatology	1
Think of being the end user (children, etc.)	1
Cartoons for illustrative purposes (persistent blooms)	1
Real time Gulf Stream location	1
Sea surface temperature of Gulf Stream water	1
Real time satellite data	1
Fact sheet with climate impacts specific	1
Integrate multidisciplinary information	1
Add "what can you do" for managers	1

Table 5
Recommendations for the delivery of a climate information decision tool from the needs assessment survey.

Deliver of climate information	Frequency of mention
Listservs	11
Use (well designed) web-based interface	10
Newsletter	5
Peer-reviewed publications	4
Social media	1
Synthesis of information (do not really need more information, just improve delivery)	1
Public service announcements	1
Use a map in the product	1

will not use this because it does not relate to my primary responsibilities", "I have more accurate data at my office", or "I will definitely use this" provided further awareness about the varied roles which managers serve and the level of their involvement in implementing decisions.

3.2. Resource management tools improved through stakeholder process

Information needs ranged from more general information about resources in the region to specific datasets tied to climate. Many data needs were reported that were not climate specific but were broader data needs that could help assess climate impacts and other stressors to the ecosystem. The most requested climate data were from peer-reviewed literature, monitoring information (delivered via the Internet), and temperature data, both at the sea surface and on the reef crest (Table 2). The multitude of information and content requested during this initial assessment clearly supported the need for a suite of decision support tools since no single tool could meet all of the managers' needs.

The pre/post survey resulted in several new insights and quantitative results. The pre-test question to identify the decision-making process illustrated broad variation in each institution. However, a general observation was that the managers who participated in the surveys provided science-based recommendations to upper-level decision makers. As such, when respondents were asked to identify their own management role, they described these roles as primary, secondary, tertiary, or quaternary, showing the dynamics of responsibilities of resource managers surveyed (Table 6). They were also asked to state the frequency at which they accessed climate information for work-related purposes: four did this weekly, three did it daily, one did it once a year, one did it six times a year, one did it monthly, and one did it every other week between May and November.

3.3. Stakeholder satisfaction

The median response for managers stating if decision support tools would be useful for making management decisions related to climate impacts to marine resources and coral reef ecosystems was a 4 (between 3 *moderately useful* and 5 *very useful*) for both the pre-test and post-test (Table 7). Likewise, the response was the same when asked if they would consider using a map-based tool and/or an ecosystem model detailing pressures and stressors to marine resources and coral reef ecosystems in future management responses. The only change in the median value of responses occurred when asked if they would recommend using a map-based query tool to other marine resource managers within their management portfolio. The median value changed from a 4 (*likely*) to a 5 (*absolutely*) in the pre-test and post-test, respectively. The post-test survey asked the 11 managers two additional questions: (1) the degree to which the prototype tools increased knowledge about climate impacts to marine resources and coral reef ecosystems; and (2) if the respondent would use the tool in the future (Table 8). The responses for the BBN and Degree Heating Weeks tools were 4; for the CHAMP site it was

Table 6
A pre-test survey was conducted to identify the type of management responsibility for each respondent. Eleven managers were asked to describe their management role in their institution. They were provided with a list of management types with descriptions and asked to select those that apply, and to rank the order of their responsibilities in each role if they selected more than one, or provided an "other" management role.

Management type	Description	Primary role	Secondary role	Tertiary role	Quaternary role
Program manager	One who manages a program that responds directly to organization	3			
Project manager	One who manages projects that directly support program goals	1	4	1	
Manager	One whose primary role is to manage staff to complete programs and projects	2	1	1	
Science manager	One who manages the collection, analysis, and reporting of organizational science	2	1	1	
Researcher	One who is technically engaged in scientific investigations and inquiry	2		1	1
Other	Coastal engineer				1
Other	Retired reef resource manager	1			

3. The responses to the final question, if they believed they would use the tools in their decision making, was yes by eight individuals for the Degree Heating Weeks tool, yes by nine participants for the BBN, and yes for ten individuals reviewing CHAMP.

4. Discussion

This project identified the climate information needs of managers working in a coupled socio-ecological system. It used participatory decision support to more closely examine the type of information needed to assist in the decision-making process. The people, process, and tools methodology helped structure a starting point for understanding the complex uncertainties tied to managing climate impacts to coral reef ecosystems and connectivity to other systems and the tools currently available.

4.1. People

Participatory decision support was used to include researchers, managers, and non-governmental organizations interested in improving the understanding of coral reef ecosystems in this process. The project developed a foundation for a common knowledge domain for future actions. The informational conversations and surveys were most valuable for translating ideas from stakeholders' minds into a list of needs and guidance for decision support tools. The interactions fostered the exploration of new tools that stimulated healthy dialogue for planning and response strategies.

Participatory decision support is a process that brings awareness to the value of multiple ideas and shared knowledge. Goosen et al. (2007) emphasized the value of a demand-driven versus a supply-driven process where tool development guided by end users can stimulate knowledge and learning among the participants. Researchers may gain a sense of a manager's needs, and the managers may see the benefits of research.

The project coordinator role was valuable for designing, developing, and implementing manager–researcher involvement. Weichselgartner and Kasperson (2010) stated that both good information and a coordinated process for sharing were requirements of knowledge and initiative for moving science to action. Liaison work was important to facilitate the process, to serve as the boundary between the two interest groups, and to provide a single point of contact to field questions and filter responses. Thus, the time commitment for a liaison must be established to ensure timely responses and individual attention to the stakeholders involved in the project. It must also be noted that the coordinator had been involved in reef-related activities for 16 years in this region and was familiar to several of the managers partaking in the project. It is believed that these long-term relationships often aided the willingness of managers to meet and participate in this project.

The term "manager" had a broad range of meanings in this study and proved to be one of the most important findings. Managers were given the opportunity to define their management role(s) in the pre/post survey (Table 6). Defining a manager's role brought clarity to the varied needs and the delivery of data. Managers may manage people, programs, or projects. They may make decisions about resource management or feed into the decision-making process by providing science or interpreting results of scientific studies to their colleagues or superiors. In some cases, they may perform one or a combination of these roles. All of those involved had some responsibility for managing coral and/or marine resources. Clarity of that responsibility was gained when they defined their job description (e.g., Project Manager, Science Manager). Ultimately, what each manager was responsible for managing was different and, consequently, there were varying needs for an end product. These needs ranged from general information to spreadsheets of data or real-time data to historical or event-driven data. The implications for climate tools are developing a product that responds to general management needs and specific needs and one that is also easily accessed and downloaded via the Internet.

Table 7
Pre- and post-survey responses recorded before and after completing tutorials for three decision support tools ($n = 11$).

Questions	Alternate responses	Pre-survey		Post-survey					
		Response	Median	Degree Heating Weeks	Median	Bayesian Belief Network	Median	Map-based query tool	Median
Do you think decision support tools would be useful for making management decisions related to climate impacts to marine resources and coral reef ecosystems?	1 Not useful	0	4	0	4	0	4	0	4
	2 . . .	1		0		1		0	
	3 Moderately useful	3		4		2		2	
	4 . . .	3		5		4		4	
	5 Very useful	4		2		4		5	
Would you consider using a map-based tool and/or an ecosystem model detailing pressures and stressors to marine resources and coral reef ecosystems in future management decisions?	1 No	0	4	0	4	0	4	1	4
	2 Doubtful	0		1		0		0	
	3 Maybe	2		3		2		1	
	4 Likely	5		4		5		4	
	5 Absolutely	4		3		4		5	
Would you recommend using a map-based tool and/or an ecosystem model to other marine resource managers within their management portfolio?	1 No	0	4	0	4	0	4	0	5
	2 Doubtful	0		1		1		0	
	3 Maybe	2		3		3		2	
	4 Likely	4		4		2		2	
	5 Absolutely	5		3		5		7	

Table 8
Post-survey responses gathered after completing tutorials for the three decision support tools ($n = 11$).

Post-survey questions	Alternate responses	Degree Heating Weeks	Median	Bayesian Belief Network	Median	Map-based query tool	Median
Rank the degree to which the tools increased your knowledge about climate impacts to marine resources and coral reef ecosystems?	1 Not useful	0	4	0	4	1	3
	2	0		3		2	
	3 Moderately useful	3		2		3	
	4	4		2		4	
	5 Very useful	4		4		1	
Do you believe you will use one of these tools in your decision making?	Yes	8		9		10	
	No	3		2		1	

4.2. Process

Curtice et al. (2012) identified the failings of resource management as a lack of resources, funding support, or inappropriate tool development. This effort sought to address the latter using a front-end assessment to characterize the types of climate information and the delivery of that information and matched those needs to researcher capabilities to avoid inappropriate tool development. It is noteworthy to mention that the involvement of end users in the development of products unlocked their need for integrated, dynamic information. This led to progress in learning and opportunity-driven solutions that otherwise would not have been identified in a confined approach where tool developers did not interact with stakeholders (Conklin and Weil, 1997).

The needs assessment process resulted in a systematic structure to characterize the situation and obtain information from stakeholders. The step-wise approach outlined by the NOAA/CSC (2003) Project Design and Evaluation training manual was used to guide the development and implementation of group sessions, informational conversations, needs assessment surveys, and pre/post surveys. Inefficiencies in the process were tied to operational aspects related to difficulties in scheduling time to meet with managers who often had limited time to complete an in-depth introduction to the topic and sufficient time to conduct the surveys. For this reason, some of the post-surveys were completed after an in-person meeting and sent to the coordinator.

An unexpected result was the development and importance of decision process diagrams (Fig. 3). The diagrams gave critical clues to where research data and tools could be applied in the decision-making process and were viewed as an important first step in participatory stakeholder engagement. The diagrams were completed in the pre/post survey, but this study would have benefited from including this important step in the needs assessment survey to clarify a manager's roles and responsibilities in the decision making.

The potential weaknesses in the needs assessment approach were bias control and sample size. Bias control was not evaluated in this project. Future surveys may consider adding bias control using additional questions in the needs assessment survey. However, sample size was limited to the number of resource managers available and willing to meet. Additionally, a smaller sample size would limit statistical analyses for more in-depth, quantitative response review if qualitative information was not sufficient.

4.3. Tools

Changes or enhancements to the climate information products in this study served local management needs by providing more detailed information about managers' preferences for the design and delivery of the prototypes (Fletcher and Hendee, 2012). Managers stressed the importance of having more information about specific areas of the reef, particularly those that fell into local jurisdictions. In addition, several expressed the need for information about both the general reef ecosystem and climate-specific data.

In summary, this research described a participatory decision support methodology consisting of people, process, and tools that guided the design of climate information for coral reef managers in southeast Florida. All three components were required to begin to address the complex issue of managing coral reefs in a changing climate. The end users, researchers, and coordinator were needed to design, create, and evaluate the prototype tools. The needs assessment survey and pre/post survey enabled end user feedback to be collected consistently. The tools were the mechanism to deliver climate data to end users. The sum of these three components was more valuable than a single piece.

Additionally, the importance of communication cannot be overstated. Communications during the surveys revealed two important points: (1) managers have different roles, experiences, expertise, and knowledge that can influence their preferences for decision making tools; and (2) development of decision process diagrams can bring clarity to where and how climate data are used in decision making. Defining management roles may seem obvious but, until they were defined and self-selected, all *managers* were viewed equally. Whereas, a Project Manager may focus on managing people using climate data to implement a project, and not use the climate tool themselves, a Science Manager may manage data, and be more likely to use a climate information tool. The decision process diagrams are a key to illustrate where climate information can be placed into decision making and shape the delivery of that information to maximize the use of climate research. Defining both manager roles and the decision process are recommended first steps in future research.

Participatory decision support proved useful for bridging the gap across the science and professional disciplines to improve the understanding of climate information and data and the application of that information in decision making. The needs assessment process fostered communication, helped identify manager needs, and matched those needs to researcher capabilities for developing prototype climate information tools. From this research, the recommended starting point for the development of resource management tools should begin with an assessment of the situation, asking managers to define their management role and jurisdiction, and to outline the decision-making process to identify where and when research data can be applied. From this vantage point, research and tool development may evolve more effectively to suit the needs of the end user and increase the likelihood it will be used.

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